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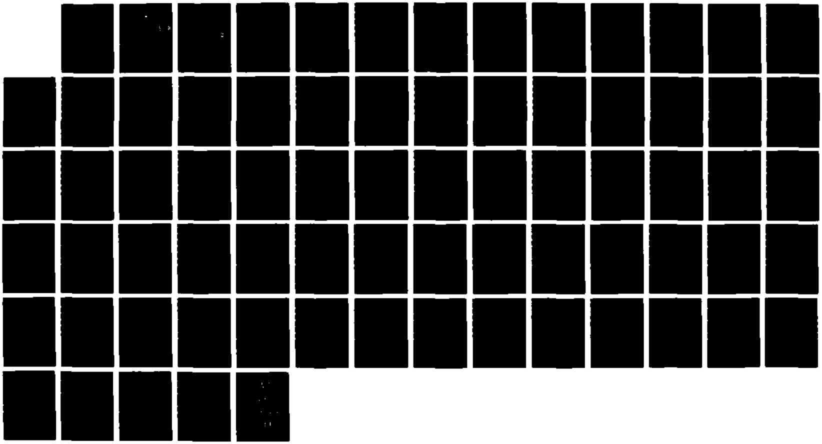

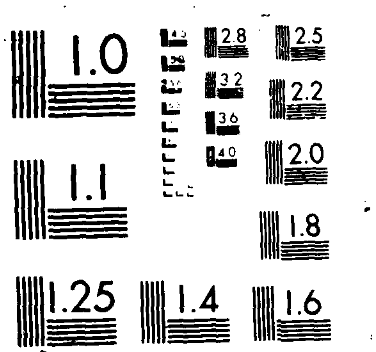
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TURBINE ENGINE MONITORING SYSTEMS: CAN THEY BENEFIT COMPONENT IMPROVEMENT PROGRAM MANAGEMENT?

THESIS

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Squadron Leader, RAAF

AFIT/GLM/LSM/87S-51

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THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Logistics Management

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Squadron Leader, RAAF

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The contribution of these individuals and the patience of my family provided the support without which this work would have been impossible. The content, analysis, conclusions, and recommendations, however, are solely the responsibility of the author.

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Abstract

The purpose of this study was to identify if the data collected by Turbine Engine Monitoring Systems (TEMS) could benefit an engine's Component Improvement Program (CIP) management.

The initial plan was to identify and assess any benefits by comparing an engine with a CIP (PWA TF30) but not TEMS against an engine with a CIP and a TEMS (GE TF34). This was not possible, however, because the TEMS data were not being used to assist with TF34 CIP management because of the lack of a Central Data Base to collate and transform the data.

Data were collected via telephone interviews with the two engine CIP managers and via a literature review. Analysis of the data provided sufficient evidence to indicate that the current methods used to estimate and track the engine duty cycle in both the TF30 and TF34 engines use potentially unreliable and inaccurate data. Sufficient evidence was also identified to indicate that TEMS data could provide more reliable and accurate engine cycle data which would improve and hence benefit CIP management.

The engine duty cycle was identified as the key to many important areas of a CIP, including engine component life usage and failure replication and diagnosis. As mentioned in the previous paragraph, the current methods used to identify an engine's duty cycle lack the accuracy and reliability that are required to manage modern gas turbine engines.

The main thrust of the recommendations is that a central data base be established so that the TF34 CIP manager can utilize TEMS data. In addition, a comparison using cost analysis is recommended to firmly establish the benefits to both long and short term engine management.

TURBINE ENGINE MONITORING SYSTEMS: CAN THEY BENEFIT COMPONENT IMPROVEMENT PROGRAM MANAGEMENT?

I. Introduction

Background

Engine Monitoring Systems. Gas turbine fan jet (TF) engines, the power plants of modern military aircraft, are becoming increasingly difficult to manage due to their complex designs, higher performance requirements, and escalating costs (Birkler, 1980:1). Despite advancement in propulsion technology the performance required by new military aircraft, especially high performance fighters, still equals or exceeds the performance of current production engines. This means that fighter aircraft often require the installed engine to operate constantly at design limits.

To enable modern TF engines to perform constantly at design limits, real time engine performance and health data are required by engine maintenance and management personnel. These data can be obtained through Turbine Engine Monitoring

Systems (TEMS). One of the first series of fully recorded trials of a TEMS on a USAF aircraft was carried out on the J85 engined T-38 aircraft of Air Training Command in 1972. The current TF34 engine TEMS evolved from the TEMS used in this series of trials (Meyer, 1986:219). The TEMS on the J85 engine continuously monitored some 24 engine parameters; however, data were only recorded if the pilot chose to or if engine parameters such as exit gas temperature (EGT) or engine revolutions per minute (RPM) dropped below or exceeded a predetermined level.

Installed testing of the TEMS fitted to the TF34/A-10 system was carried out from 1978 through 1980. Full scale modification of A-10 aircraft at Barksdale AFB began in 1982. Completion was achieved in 1983. The TEMS data are used for maintenance and spares management and are also used to track limited life components for short term and long term trending (Meyer, 1986:214-233). Using TEMS to automatically monitor and record engine parameters during flight operations aids the maintenance decision making process by removing some of the uncertainty (Birkler and Nelson, 1980:4).

To date the USAF has primarily been concerned with the short term benefits of TEMS such as improved flight safety, engine reliability, scheduling, maintenance tasking, and logistics support. Realization of these benefits has been researched and analyzed in many reports compiled for the USAF (Birkler, SAE, Fleming, Sallee).

One report in particular, on TEMS experience to date, concluded the following :

> "1. The maintenance cost savings used to justify a new monitoring system are unlikely to materialize over the short term.
>
> 2. Historically, tests of engine monitoring have not yielded conclusive evidence on the value of engine monitoring, because the aircraft sample was too small and programmed flight hours were too few."(Birkler,1980:87).

In addition to these short term benefits, such as improved maintenance diagnostics and engine in-flight integrity, there are long term benefits, such as improved component design, better Low Cycle Fatigue (LCF) management, and improved engine and component testing to be gained from using TEMS data (Birkler, 1980:7).

Component Improvement Program. The term Component Improvement Program (CIP), previously known as Product Support Program (PSP), refers to a support program set up by an engine manufacturer to provide engineering services to correct design and material deficiencies during the service life of an engine. To participate in the CIP a military user must contribute a set amount of dollars each year. This sum is made up of engineering and administrative support costs plus a percentage cost based on the percentage of the total number of engines owned by all the participating operators from each country. This percentage cost is to cover the research and develo, ent required to provide engine component improvements. The RAAF typically pays AUS$2.5 million (based on 1984-86 CIP contract) every three years for 68 TF30-P3 engines to participate in the TF30 CIP (TLO-OCALC). This is a small sum compared to the amount paid by the USAF for CIP participation for the many different engine types in the USAF inventory. In 1985 CIP funding was set at approximately $140 million and required expenditure was approximately $180 million while in 1986 funding was set at $110 million and actual expenditure was approximately $180 million. Funding for 1987 has been set at $110 million with the actual expenditure forecast at $160 million (ASD/YZLE, 1987).

Each engine type that has a CIP also has a CIP manager. This can be a single person or an office of personnel. The CIP manager is responsible for watching engine trends and compiling data from engine users. This manager is also responsible for managing CIP funds to ensure that the user's more important engine problems receive priority funding. This prioritization process ensures that the engine manufacturer is concentrating on the problems of most concern to the user. A problem or deficiency is worked on only if there are sufficient funds available. If all the operators have the same priorities then the costs are shared on a percentage basis as discussed above. However, if a single operator requires a solution to a particular problem that is only of concern to that user, then the one user must provide the total funds for CIP involvement on that item.

A CIP manager's responsibility (TLO-OCALC,1987) is made more complicated by the large number of items which compete for CIP funds as an engine matures. The task of determining which item receives priority and which items will lie dormant is the responsibility of the CIP manager. The engine CIP manager will usually base such a decision on available component failure history data or on Accelerated Mission Test (AMT) data. The AMT program is an endurance ground test program in which an engine is continuously run through a simulated engine duty cycle until a component failure occurs or until a predetermined number of equivalent flying hours (EFH) is reached. An engine's duty cycle is based on the pattern of engine throttle movements during an aircraft's approved flight pattern. The aim of the AMT program is to ground test components of the particular engine type by logging a number of EFHs that is well in advance of the largest number of hours logged by any in-service engine.

The relationship between hours and cycles is based on knowing or estimating an engine's duty cycle during one hour of operation. An engine's duty cycle is usually estimated during engine design and compared against initial flight profiles. If a squadron changes its role the flight profiles may change and thus greatly change an engine's duty cycles. This could result in incorrect CIP management if these changes are not implemented in the ground test program.

Previous experience has shown that duty cycles used during engine development, military qualification testing, and the subsequent AMT program usually grossly underestimate the frequent power cycling that occurs during normal operation (Birkler, 1980:9). A gross underestimation of duty cycles on an engine with a reliability centered maintenance philosophy is very dangerous. When the hours of operation are converted to cycles to determine remaining life the projection will be greater than actual remaining life. The probability of early engine component failure is consequently greater than expected.

CIP and TEMS Interaction

The main aim of the CIP manager is to use the available funds to achieve the best component improvement results. The best results involve satisfying operational, safety, and engineering deficiencies. To achieve this aim effectively the CIP manager requires access to the best, most accurate, information available.

Accurate failure data relies on knowing the exact cause and sequence of failure for a component. This is not always easily determined, especially for catastrophic failures. Without TEMS, determination of cause relies in part on the pilot reporting the sequence of events and engine parameters leading into the failure or failure indication. Reliance on the pilot or other human observer can introduce error through bias and missed observations. In addition, if there are delays in reporting flight profile variations, and hence true engine duty cycles to the AMT program, the cycle to hour relationship will be inaccurate which would make any assumptions based on the AMT results also inaccurate.

Whether a CIP manager would change priorities if more accurate data were available is not known. The use of TEMS on engines represents an opportunity to accurately record an engine's duty cycle and any component failure sequences without bias or human error. If more reliable data would alter priorities and fund allocation of a CIP, then providing a CIP manager with such data becomes important. The recommendations made in a report on US military TEMS experience up to 1980 were that:

> "The scope of US military turbine engine monitoring systems should be broadened to include the valuable contribution that information feedback can make to the designer over the long term. Of particular importance is the correlation between testing and operational duty cycles."(Birkler, 1980:89)

Problem

The problem is that CIP managers and engine manufacturers estimate an engine's duty cycle, LCF usage, and other operational environment factors by using potentially unreliable and approximated data. While more reliable and accurate data are collected by TEMS, these data are not presently available to engine CIP managers in a usable form.

Research Objective

The objective of this research was to identify whether making TEMS data available to an engine CIP manager in a usable format would produce better long term engine improvements under CIP than the data presently used. In particular the areas of engine duty cycle determination, engine life usage management, and failure replication and resolution require investigation. A second subsequent objective was to establish if the TEMS data collected on the TF34 engine were being utilized by the TF34 CIP manager.

Scope

The comparison of CIP management with TEMS versus management without TEMS was based on two specific engine types. The two engines were chosen so that one had a developed CIP history but did not have a TEMS installed. The other engine was chosen such that it had both a CIP history and an in-service TEMS history. The time frame for historical data was be limited to seven years. Seven years was chosen because only very limited TEMS in-service data older than seven years was expected to be found.

Specific areas of investigation included the AMT program, which is used by the CIP to substantiate component design and failure analysis; monitoring of components that are subject to short, Low Cycle Fatigue (LCF) lives; and hot section component design. Determination of benefits involved presenting the expert opinion of the CIP and TEMS managers with regards to management or engineering improvements.

Limitations

A limited history was available from which to draw data on fully implemented TEMS and from which to decide if any benefits were available for a CIP manager. The main source of information was the current CIP managers for the TF30 and TF34 engines. Additional information was sought from the TEMS manager for the TF34 system. The missions of the two aircraft types that the engines are installed in might influence the particular data needs as well as the priorities assigned by CIP. This might produce differences between the performance requirements for the two engine types that could conceal any improvement achieved by linking CIP and TEMS.

Research Development

Prior to developing the interview questions and performing the data collection a complete literature review was conducted and formed the basis for Chapter II. This consisted of a study of past research into TEMS benefits and any CIP interaction. Following the literature review interview questions were developed and then the CIP managers were interviewed. The method of data collection is summarized in Chapter III.

Once the interviews were completed the data collected from the literature review were combined with the interview data and analyzed. This analysis is outlined in Chapter IV.

Chapter V contains a summary and conclusions regarding the use of Turbine Engine Monitoring Systems (TEMS) to assist engine Component Improvement Program (CIP) management, as well as recommendations for the development of TEMS/CIP interaction and application to future aircraft engine systems.

II. Literature Review

The main literature search consisted of a Defense Technical Information Center (DTIC) request for articles referring to any of the following:

a. Component Improvement Program (CIP)

b. Turbine Engine Monitoring Systems (TEMS)

c. Aircraft Engine Monitoring

d. Engine Monitoring

c. Engine Usage Monitoring

Only unclassified reports and articles were reviewed. In addition, the Propulsion Directorate of Aeronautical Systems Division provided a copy of the minutes to the 13 August 1986 Air Force Engine Monitoring Systems Meeting. The goal of this meeting was to establish an Engine Monitoring System (EMS) engine review group (Meyer, 1986:2).

Much of the literature dealt with the short term benefits of TEMS such as improved fault diagnosis, corrective maintenance, and flight safety through a better knowledge of the engine condition. Some of the literature made reference to long term benefits such as improved engine and component design and an improved picture of the engine operating environment, all of which involve engine CIP (Birkler,1980; SAE,1986; Sallee,1977). These discussions however, were in the recommendation section because no real research had been completed on TEMS- CIP interaction. The literature was directed towards finding short term benefits of TEMS.

Short Term Benefits

During the Air Force EMS meeting the A10 TEMS manager stated that benefits seen to date included increased readiness, improved sustainability, improved flight safety, reduced mission aborts, improved maintenance and planning, and improved spares projection (Meyer, 1986:Attachment 6, 9). These benefits allowed for life cycle cost savings of $178.65 million in 1984 and the projected savings for 1994 was $341.15 million (Meyer, 1986:Attachment 18, 47). From a system manager's point of view the important benefits of TEMS are:

> "TEMS is providing an early warning of subsystem, (i.e., engine) functional degradations during flight. Utilizing such information; timely maintenance and corrective repair actions are being performed before the degradations can culminate in catastrophic failures contributing to extensive maintenance or possible loss of aircraft." (Meyer, 1986:Attachment 18, 13).

This was supported during the discussion on A10 CEMSIV implementation. CEMSIV is a base level implementation of CEMS. A CEMSIV system was developed and installed at Barksdale AFB in October 1982 and was used for storage and management of A10, TF34 TEMS data. Demonstrated benefits have included reduced scheduled maintenance, reduced unscheduled maintenance workload, automated tracking of life limited parts, 70% reduction in required engine trims, 81% reduction in throttle alignment checks, and 50% reduction in the number of water washes required (Meyer, 1986: Attachment 8, 42,43).

The recommendations that were made concerning CIP identified three main areas for potential benefit to CIP management. All three areas were tied to obtaining an accurate and reliable picture of an engine's operating environment and all three influence CIP management, engine design, and component design to a large degree (Birkler, Sallee, SAE, Vincent). These three areas of possible benefit were:

1. Improved analysis and understanding of an engine's operating environment and duty cycle.
2. Improved understanding of engine component life usage and hence better management of Low Cycle Fatigue (LCF) and other life limiting factors.
3. Improved capability to replicate and diagnose in-service failures in ground tests.

In addition to these main areas, the use of a central data base for storing and transforming TEMS data for use by engineering and CIP managers was also discussed (Meyer, 1986: Attachment 18, 47).

Engine Duty Cycle

The benefits that are often overlooked when reviewing TEMS performance are the long term benefits. These include benefits in engine design, testing, product/component improvement, and management policy (Birkler, 1980:7). One of the major, and often overlooked, long term benefits is being able to obtain a true understanding of an engine's duty cycle.

> " Engine problems are often rationalized, citing material or design deficiencies, by implying that the engine is highly advanced in technology. This is certainly true in some cases, but research reveals that the operational environment and the severity of the engine's duty cycle are not fully appreciated, also resulting in substantial problems not expected or accounted for during design .... In short, engineering awareness of the operational environment has been inadequate, contributing to low initial reliability, which must be corrected during extensive post Military Qualification Test (MQT) engineering during the Component Improvement Program.
>
> The testing cycles used during engine development and MQT qualification usually grossly underestimate the frequent power cycling that occurs during operation. An expected long term monitoring benefit is that the engine's duty cycle will be highly visible." (Birkler, 1980:9).

This summary supports what was stated at the 1977 Propulsion and Energetic's Specialist's Meeting when discussing the F100 engine Accelerated Mission Test program. The report suggested that one of the most significant discoveries was the actual number of full throttle excursions that was measured versus the number predicted during design. This showed that military qualification testing requirements were significantly out of touch with actual usage (Sallee, 1977:33).

In the evaluation of the B-1 aircraft central integrated test subsystem (CITS) General Electric, the B-1 engine (F101) manufacturer, stated that once the collected data were analyzed the differences between the 'Design Mission' used for engine design and qualification testing and the actual duty cycle had to be completely reevaluated. This analysis resulted in a complete revision of the AMT mission profile for F101 endurance testing under the CIP (Vincent, 1980:109).

A knowledge of the actual engine duty cycle is important when determining component life usage. Every time the throttle is moved an engine goes through RPM and thermal excursions. Each time this occurs the life of the major rotating assembly components such as compressor disks and blades, turbine disks and blades, and combustion components is reduced. Each approved mission profile for an aircraft has an associated engine mission profile or duty cycle. However, because of differences in technique and the rigorous demands placed on the pilots of modern fighter aircraft, the exact engine duty cycle rarely resembles the approved duty cycle (Birkler, 1980:73). The Royal Air Force has found, for example, the amount of engine life consumed depends, to an important extent, on the mission flown and on how the engine is used during the mission. They also found that a major contributor to reduced engine life is the cumulative effect of small power transients (Birkler, 1980:73).

Failure Replication and Diagnosis

The one area that consumes most CIP funds and AMT running time is that area involved with reproducing component failures in the test cell in the same way they occurred in service (Lewis, 1987). Replication and diagnosis of in-service faults or failures is essential to allow for component redesign or new designs. One of the main reasons for the difficulties involved in trying to reproduce an in-service problem is the lack of data about the engine and its environment and especially the cause and effect data needed to duplicate the failure sequence. Unless an aircraft is fitted with a TEMS it is up to the pilot to monitor his instruments and record important parameters. The pilot, however, is usually too occupied with the results of the failure to accurately record engine parameters. An interviewed HQTAC Maintenance Officer (Baker, 1980: A22) said:

> " The TAC mission is conducive to monitoring because the mission impacts engine health. During the Holloman TEMS tests, pilot reported discrepancies often occurred when the aircraft was operating outside the established profile. TEMS data was used to verify this."

Having accurate duty cycle data not only helps in the design of modifications and new components following a fleet failure trend, but it can also assist in accelerating the maturation of a new engine model. This is important because it reduces the amount of retrofitting that is required as the engines are manufactured. General Electric fitted an IECMS to the new F404 engine installed in the F-18 aircraft. Their findings were summarized as follows (SAE, 1986:26):

> " Many times, infrequent problems that occur in the flight environment are nearly impossible to duplicate on the test stand. Lack of insight into these problems delays their solution, resulting in a less mature engine and greater retrofit costs when the solution is found.

Acquiring pre and post event data as the anomaly occurs during flight provides the insight to understand the cause of the problem. The benefits have been a more effective Component Improvement Program and a more rapid development of the engine."

Engine Component Life Usage

An accurate knowledge of the rate at which an engine's component lives are being consumed is required for LCF management and bill-of-material selection during redesign. Both of these depend on having a knowledge of the actual operating environment of the engine, especially the thermal cycles and vibration signatures. The engine component life usage is determined during engine design but this rarely reflects actual usage. One study (Sallee, 1977:4) has shown that actual engine usage can differ from the basis for design and that actual thermal cycles in an operational engine can be as much as ten times higher than original design considerations.

Engine aging depends on the running time of an engine and is accelerated by operation at high internal temperatures. Cyclic throttle excursions result in temperature transitions in the major rotating assemblies in an engine and have a predominant relationship to the remaining life of components. This knowledge is incorporated into the analysis of LCF and hot section factors (DeHoff, 1978:11). Therefore, the better the understanding and the more accurate the picture are of the actual duty cycle of an engine the more reliable and accurate will be the design and modification of components, especially in the areas of LCF and thermal fatigue. This opinion was supported by the TF41 TEMS trials. Early in the IECMS program, design limits were programmed into the system to monitor components that had not been previously tracked. Many components were found to be operating beyond their actual design life because their actual life usage rates were well above the rates predicted during engine development. This resulted in the development of new design limits consistent with IECMS tracking (SAE, 1986:14).

Similar trials for the B-1 aircraft Central Integrated Test Sub-system (CITS) revealed the same deficiencies between design life usage and actual life usage for the F101 engine. The collected and analyzed data resulted in the reevaluation of the differences between actual engine usage and the 'Design Mission' usage that was used for engine design. This analysis resulted in a complete revision of the AMT mission profile for the F101 endurance tests carried out under the F101 CIP (Vincent, 1980:109).

In a similar program the Royal Air Force (RAF) set a goal of achieving optimum useful lives for engine major rotating components through understanding the extent of deterioration and life usage as a result of thermal and low cycle fatigue, creep, and thermal shock (Birkler, 1980:67). To achieve this goal a system known as the Engine Usage Life Monitoring System (EULMS) was developed and installed on several aircraft types. Application of EULMS data has yielded significant insight into an engine's operational duty cycle. The British have found, for example, that the amount of engine life consumed depends, to an extent, on the mission flown and how the engine is used during the mission. They also found that a major contributor to reduced component life is the cumulative effect of small power transients (Birkler, 1980:73). The importance of engine usage tracking increases as more analytical techniques are developed to transform these data into a set of measurements that are meaningful for engine life management (Vincent, 1980:108).

TEMS Data Base

An important part of developing techniques for transforming TEMS data into useful information is the use of a good data base. The USAF has the Comprehensive Engine Management System (CEMS). The objective of the CEMS is to support reliability centered maintenance policy while improving the efficiency of the engine maintenance process by providing access to engine performance information to Air Force personnel at appropriate levels and in an appropriate format (Meyer, 1986:Attachment 8,4). A further extension of CEMS is CEMSIV, a base level implementation of CEMS. A CEMSIV system has been developed and installed at Barksdale AFB and is used for storage and management of A-10, TF34 TEMS data (Meyer, 1986:Attachment 8, 42). The CEMS system is a central data base (CDB) at Tinker AFB designed for access by organizations such as ALCs, AFLC HQ, and MAJCOM HQs. The initial plan for CEMSIV was to link it with the CDB so that the CDB data could support fleet visibility for readiness, depot level maintenance, maintenance analysis, and CIP (Fleming, 1982:Vol I, 14).

As of August 1986 the TF34 CEMSIV system had not been linked to the CDB at Tinker AFB (Meyer, 1986:5). This means that TEMS data were not being stored and transformed into meaningful information for engine managers or CIP managers. All the available engine trend data and engine usage data were being stored at base level and hence could not be accessed by CIP management. This link still had not been accomplished in 1987 (MMP/BRE, 1987).

Summary

Much of the literature indicates that benefits may exist for CIP management from the analysis of TEMS data but it also indicates that using these data is an iterative process that requires stimulation from both the TEMS managers and the end users of the TEMS data. One major area of possible benefit, that became evident from the literature, is in the determination of the actual duty cycle of an engine. However, many of the perceived benefits for engine mangers have been discovered whilst looking for short term benefits for maintenance management and engine utilization. Input from engine CIP managers was not present. There needs to be a determination as to whether CIP managers require a better means of determining an engine's duty cycle and if they believe TEMS data could provide that means. If TEMS data were being used to assist CIP management, then a comparison of CIP with TEMS versus CIP without TEMS could be made. The means by which these issues were evaluated is presented in Chapter III.

III. Method

The literature review has identified three main areas of possible benefit for a component improvement program (CIP) manager from the use of turbine engine monitoring system (TEMS) data. The first main area is that of accurately identifying an engine's duty cycle. This leads into the other two areas of failure replication and diagnosis and engine life usage determination, both of which rely on having an accurate and reliable understanding of the engine duty cycle. What was not shown in the literature review was whether the current methods used by CIP managers to identify an engine duty cycle were adequate.

To determine if current methods are adequate or if TEMS data could benefit a CIP manager, particularly in any of the three identified areas, telephone interviews were conducted with the two CIP managers. The purpose of these interviews was to establish how CIP managers estimate the duty cycle for engines and whether they believe TEMS data could offer a more reliable and accurate alternative.

Research Design

Engine Choice. Two engine types were required in order to form the basis for comparison. The selection of the engine types for this research was based on two major characteristics. The first requirement was that the engine should have an active and well developed CIP. The second requirement was that at least one engine should have a fleet wide installation of a TEMS which would mean that a history of TEMS data and its uses should be available.

The engine selected that had an established CIP but not a TEMS was the TF30 engine installed in F-111 aircraft. In addition to meeting the primary criteria, the TF30 engine was also chosen because it was in service with both the USAF and the RAAF and because of this writer's past experience as a TF30 system engineer. Only one engine with CIP but not TEMS was chosen because, although the engines may vary, the CIP management for all USAF engine types is similar.

The choice of an engine with a CIP and a fleet wide TEMS was limited since only one engine type in the USAF inventory had a historical base for both CIP and TEMS. The TF34 engine installed in A-10 aircraft had a TEMS history dating back to 1978 and the entire A-10/TF34 fleet had been modified by 1983 (Meyer, 1986:214-233).

Data Collection. The initial plan was to collect data on how the TF30 CIP manager obtains information to assist in the CIP and compare the outcome to that of the TF34 CIP manager who has access to TEMS data. However, preliminary investigation revealed that the TF34 CIP manager does not use TEMS data to assist with CIP management because it is not presented in a usable format (Appendix B page 55). This changed the research design to one that resembles the Delphi technique. The Delphi technique involves asking a sample population a broad range of questions and then using the replies to formulate a tighter set of questions. This procedure is usually carried through up to four or five iterations (LSR, 1987).

In this research both the TF30 and the TF34 CIP managers were contacted via telephone to establish background data to enable construction of an interview questionnaire. The questionnaire was then reviewed to ensure that no bias was being introduced by any of the questions. Each of the selected CIP managers was then interviewed per the established questions. The questions and the CIP managers' replies are at Appendix A and Appendix B. No subsequent iterations of interview question revision were considered useful, given the limited number of experts available and the technical nature of the data under review.

In addition to the data collected from the CIP managers, data were also collected via the literature review. Although the majority of the literature referred to short term benefits associated with TEMS there were limited references to long term benefits. In particular, three main areas were referenced. These were, the benefits associated with an improved knowledge and understanding of an engine's duty cycle, an improved understanding of engine component life usage and hence a better management of low cycle fatigue lives, and improved failure replication and diagnosis through an improved understanding of the operational environment.

These three main areas were then used to further refine the structure and purpose of the interview questions. Because the TF34 engine had a TEMS installed the questions for the TF34 CIP manager had to be slightly different from the questions for the TF30 CIP manager to avoid any possible bias on the part of the TF34 CIP manager.

Variable Description. The main cause for aging in a gas turbine engine is the change in operational temperature and rotational speed that the major rotating components are subjected to (Dehoff, 1978:11). These variations are a result of throttle movements that occur during an aircraft's mission. An engine's duty cycle comprises all the throttle movements from engine start to shut down and the engine duty cycle for a specific unit role is called the approved mission profile. The operational environment of an engine was defined by OC-ALC MMP/RES as:

> "... all inputs and outputs dealing with producing a propulsive force. This includes fuel flow, mass air flow, throttle movements, operating temperatures, and engine revolutions per minute (RPM) excursions" (Appendix A: 48).

Clearly, the engine duty cycle or mission profile plays a large part in an engine's operational environment and component life usage. Once the engine mission profile and operating environment has been estimated or determined the data are then used to develop the engine AMT duty cycle.

The AMT is part of the CIP that is run by the engine manufacturer and involves qualifying new component designs and component modifications by ground running them in an AMT engine according to the estimated duty cycle. The items are run continuously at a rate that is accelerated compared to normal squadron usage. Component lives are counted in hours of operation and are calculated by dividing the known cyclic life of a component by the estimated number of engine cycles per hour of operation based on the duty cycle of the engine. The AMT test bed engine is also used to replicate in-service component failures or conditions that lead to failures to allow for effective redesign of components. In addition to the AMT program, test benches are also used to replicate faults in ancillary equipment such as fuel controls and fuel pumps. This testing has to be slotted into the overhaul and repair test schedule for similar components. Any data that can help to reduce the time required to reproduce an in-service failure by reducing test bench or AMT time requirements would be considered beneficial to CIP management.

Data Analysis. Once the interview data were collected the opinions of the two CIP managers were compared to find any areas of agreement on the advantages or disadvantages of using TEMS data to assist in CIP management, particularly in any of the three areas identified by the literature review. The literature review data were then used to support the expert opinion of the CIP managers. In addition, the reasons for not using TF34 TEMS data to assist with TF34 CIP management were also investigated.

The CIP manager's main objective is to achieve maximum engine component reliability and maintainability using the available CIP funds. Therefore, any process or procedure that improves the effectiveness or efficiency of CIP management is beneficial. In particular, improvement in the areas of AMT expenditure and utilization, fleet degradation trend analysis, increased lead time for component improvement requirements, and reducing fault diagnostic time requirements can be considered beneficial to CIP management. Any indication or proof that an increased effectiveness or efficiency can be achieved in any of these areas through the use of TEMS data for CIP management can be considered evidence that the use of TEMS data can benefit CIP management.

IV. Analysis

Telephone interviews were conducted with the TF30 Engineering Unit Chief (MMP/RES) at Oklahoma City Air Logistics Center (OC-ALC) and with the TF34 Project Engineer (MMP/BRE) at San Antonio Air Logistics Center (SA-ALC). The record of the TF30 interview is included as Appendix A and the TF34 interview record is included as Appendix B. Data were collected from MMP/RES at OC-ALC first and then from MMP/BRE at SA-ALC. The plan was to compare CIP management without TEMS (TF30) against CIP management with TEMS (TF34). The interview with MMP/BRE, however, revealed that the TF34 TEMS data are not used by the TF34 CIP manager (Appendix B:55).

The aim of the interviews was then changed to that of collecting expert opinion to identify whether the CIP managers believed TEMS data could produce better CIP results than the data currently used and if so how. As discussed in Chapter III, three main topic areas were chosen. These were improved understanding of the actual engine duty cycle, improved surveillance of actual engine component life usage and hence improved management of low cycle fatigue (LCF) and other life limited components, and improved ability to replicate and diagnose in-service failures and hence improve repair and new component design and engineering.

Duty Cycle Determination

TF30. The operating environment, and hence the mission profile, for the TF30 engine is estimated using two different procedures so as to allow for cross-checking. MMP/RES stated that the TF30 AMT duty cycle is calculated by Pratt and Whitney using the same methods. Method one involves field visits by OC-ALC MMP personnel to the various TF30 operating squadrons to conduct interviews and discussions with pilots and maintenance personnel. The main area of discussion with the pilots is the position and movement of the throttle that occurs during a normal mission. As discussed in Chapter II, the operating environment of a pilot in a military aircraft does not lend itself to making accurate records of engine parameters.

The second method uses data that are recorded on the aircraft structural data recorder which has been installed on twenty percent of the F-111 aircraft fleet. This device records many airframe cyclic events but also records gross fuel flow, altitude and mach number. These data can be used to construct a sketchy picture of the engine operating environment when used with the field interview data. This method is also questionable. An accurate picture of the engine mission profile cannot be constructed using such limited data. Two of the most important parameters for establishing an engine duty cycle are engine RPM transitions and engine throttle position (Appendix A: 50). Neither of these are monitored by the F-111 structural data recorder (MMP/RES, 1987). In addition, the summary of the RAF Engine Usage Life Monitoring System (EULMS) trials stated that small throttle excursions were significant and that every pilot will fly his mission differently in terms of engine usage. The summary concluded that all operational engines need to be monitored in order to construct accurate mission profiles (Birkler, 1980:73).

TF34. Although the TF34 engine has a full TEMS installed, TEMS data are not used to develop the engine duty cycle (Appendix B: 55). As part of the TF34 CIP, the engine duty cycle is calculated using data from the A-10 aircraft Velocity/Gravity/Height (VGH) tapes. The VGH tapes record velocity, gravity and height data during an A-10 mission. In addition this VGH system also records the engine throttle position. The TF34 AMT duty cycle is then developed using these data.

The problem with this approach is that while this method would produce a more accurate picture of the TF34 duty cycle than the duty cycle picture produced by the TF30 CIP, it would still not be a totally accurate picture of the engine mission profile. Data on RPM excursions and thermal cycling are required to provide a complete estimate of the mission profile and engine life usage. In addition, the VGH data are not received frequently and hence further reduce the credibility of the estimated duty cycle.

Both the TF30 and TF34 CIP managers agreed that accurate and reliable data were required to correctly establish an engine duty cycle or mission profile. The TF30 CIP (MMP/RES) manager stated that a TEMS could provide the required data but the data would only need to be collected for a representative sample to establish the mission profiles. The RAF EULMS trials tend to indicate that all engines would need to be monitored. This would also be the case if trend analysis were required. The TF30 CIP manager stated that the number of engines fitted with a TEMS would depend on a cost-benefit trade-off (Appendix A: 50). The TF34 CIP manger (MMP/BRE) stated that the VGH tapes provide an adequate picture of the duty cycle but the data's usefulness is limited because of the infrequent delivery of the tapes (Appendix B: 56). If TEMS data were available in a usable format on a regular basis it would provide a more reliable means of identifying the duty cycle (Appendix B: 57). As previously stated two of the most important parameters are the throttle position and the engine RPM excursions. Without the RPM data accurate estimation of thermal stress and component life usage is not possible (MMP/RES, 1987). The A-10 VGH tapes do not contain engine RPM excursion data and so even if the VGH data were delivered on a regular basis, its usefulness would still be limited. In isolation the throttle position data is only partly useful for identifying the actual engine duty cycle.

The mission profile for any engine will differ from squadron to squadron and may differ significantly from pilot to pilot, but the lives of major components in both the TF30 and TF34 are determined by estimating a duty cycle that is proposedly representative of the entire engine fleet (MMP/RES, 1987, MMP/BRE, 1987). This means that some components may be operating beyond their safe life or may be removed from service with life remaining. For example, the component lives for TF30 engines used by the RAAF are the same as the lives used by the USAF but the aircraft missions are significantly different. The typical RAAF F111 mission involves an anti-shipping role and requires low level operations involving much throttle manipulation. Similarly RAAF land operations require of low level terrain following radar operation which again involves frequent throttle manipulation. In contrast, many of the USAF F111 missions involve strategic operations which require less throttle manipulation. Under the CIP Pratt and Whitney are currently trying to develop a duty cycle for RAAF TF30 engines using data from airframe recorders. However, the data are limited and the accuracy and reliability of the estimated duty cycle which is developed will be questioned due to the lack of a credible data source (TLO, 1987).

An accurate and reliable identification of the duty cycle is very important as it is required by many of the functions of the CIP. The AMT program is based on the estimated duty cycle and hence all modified or redesigned engine components are qualified using this cycle. Another very important area in which the duty cycle is used is in the area of component LCF and thermal fatigue life estimations or in general the area of calculating actual component life usage. All of these actions require accurate duty cycle data. These data are not presently recorded.

Engine Component Life Usage

The expected operational lives of engine components are estimated or determined through product testing carried out by the manufacturer. The component lives are reported in terms of the number of cycles that can be used before low cycle fatigue, thermal fatigue or creep cause the component to become unsafe or out of tolerance. The component lives are stated in terms of hours of operation, cycles or other description of cycle usage rates. Whichever terminology is used, the rate at which the life of the component is used is calculated from the estimated duty cycle.

Because the reliability and accuracy of the duty cycle are questionable (as established above) the calculation of component lives is believed to be always very conservative (Lewis,1987, Aguilar, 1987). The consequence of this is that components may be removed and disposed of before their actual useful life is consumed because the calculated life has such a conservative safety margin.

Both MMP/RES and MMP/BRE pointed out that even though the LCF live usage calculated using TEMS data may be more accurate and hence less conservative, the component lives may not necessarily be increased but may be decreased. TEMS may reveal a more severe duty cycle than is currently used and hence would suggest shorter LCF lives. The estimates that are currently considered to error on the side of safety and conservation, may actually be highly risky estimates. The cost benefit in this situation would not be in terms of extended component useful life but in terms of reduced unexpected component failure and possible total system loss.

The major life limiting factor in a major rotating component is its LCF life. LCF is affected by rotational speed, rapid variations in speed, and by temperature changes. All of these factors can be monitored using TEMS. The component LCF life is determined, in hours of operation, by deriving an engine cycle to hour ratio from the estimated duty cycle. If the CIP manager and the engine manufacturer had access to TEMS data, then more accurate and less conservative LCF lives could be calculated through having an accurate and reliable picture of the engine duty cycle. More accuracy and less conservativeness may also mean less risk, since a truer picture of the cause and effect of engine component failure could be developed.

OC-ALC MMP/RES concurred and said that a better understanding of the actual duty cycle and actual cycles per hour would help to more accurately identify crack origins and crack propagation rates. This would help to develop more accurate LCF life estimates. TEMS data could also be used to enable components at different operating units who fly different missions to have different LCF lives assigned. SA-ALC MMP/BRE concurred that a major benefit of TEMS data, if processed properly, would be more accurate LCF lives as well as specific LCF lives that are tailored for specific missions.

Two other factors that influence component design and life are thermal cycling and vibration. TEMS data can provide a history of thermal cycling and a vibration signature for monitored engines. These data can be used to help simulate failure conditions when testing components in the AMT. OC-ALC MMP/RES also suggested that a TEMS record of thermal cycling and vibration signatures could also be used during component design to assist engineers in choosing component materials. Components could be manufactured using less conservative safety margins, due to the accurate environment data provided by TEMS, and hence reduce component costs.

On this topic of thermal cycle data and vibration signatures, SA-ALC MMP/BRE commented that there is a lot of variance in such TEMS data and that a historical data base would be required to make it useful for CIP management. A vibration or thermal signature is not very useful on its own, but when a history of signatures can be stored for trend analysis and cross-referral the information can reveal a great deal about the life usage within an engine and can be used to predict fleet deterioration. A data base is required to collect and collate signature data to allow for appropriate analysis. Every engine will have a different signature and each engine's signature will change significantly following component replacement, repair, or overhaul. If signature analysis is to be used for fleet deterioration predictions every engine will require a TEMS. MMP/RES and MMP/BRE agreed that TEMS data would be very useful in identifying component failure trends and monitoring the deterioration of the engine fleet.

These data could then be used to begin a component replacement program before component failure or operational restrictions indicated a problem or a trend. The big benefit to CIP would be that the research, development, and testing (RD&T) of the modification or replacement component could be spread over several years rather than making it a priority CIP item because engine shortages were occurring. This would mean that the cost of RD&T for a component could also be spread across several years instead of causing a redirection of funds from other items because it became a priority item. AMT testing of the proposed component improvement could also be better planned for if failure trends could be recognized in advance.

Failure Replication and Diagnosis

One of the concerns of the CIP is reproducing isolated incidents of component failures. This is usually accomplished by attempting to reproduce the operating conditions that led to the failure based on the estimated duty cycle. MMP/RES said that TEMS data would assist the AMT program by better defining the duty cycle and could also reduce AMT run time by helping to accurately establish the operating environment before, during, and after the failure.

Of particular concern to both MMP/RES and MMP/BRE is the resolution of engine fuel control problems and related engine stalls and engine over-temperature incidents. This was the only area in which MMP/BRE used TEMS data to assist in failure resolution. A project has commenced to create a specific data base for TEMS fuel control data (Appendix B: 56).

A large delay in the CIP is caused by the wait for AMT test time. This involves waiting for the current AMT run to finish and then for the engine to be torn down for analysis. If funds are available and there are sufficient items that require qualification the engine will be rebuilt with the new or modified components and then run. Much of the run time and analysis time is consumed with trying to confirm that the test results accurately reflect actual engine usage. This confirmation is achieved by comparing the AMT engine condition with actual in service engine usage at various stages in the AMT run. MMP/RES concurred that AMT run time could be reduced if the duty cycle was derived from TEMS data and actual AMT progress could be checked against TEMS information. In addition the use of TEMS data would increase confidence in the AMT results and hence reduce the amount of cross-checking required.

Reducing AMT program time would assist CIP management in many ways including reduced cost through shorter qualification runs and quicker introduction of new or improved components by having greater access to AMT time. Pratt and Whitney charge $375 per week, based on engine running for 20 hours per day for 7 days per week, for CIP AMT runs. Fuel costs for the TF30 engine are approximately $5290 per hour. This cost is based on a fuel cost of $0.75 per gallon and a usage rate of 3000lb per hour at military power and 30,000lb per hour using full afterburner. A typical AMT run uses military power for 85% of the run and afterburner for 15%. This results in a total weekly running cost of $740,975/week (TLO, 1987). Possible savings as a result of TEMS are difficult to predict because the amount of time saved would be dependent on the nature of the on-going investigation (MMP/RES, 1987). Nevertheless, the potential for significant cost savings, or, reallocation of AMT engine test time to solve other problems sooner appears substantial.

Other Areas of Benefit

OC-ALC MMP/RES commented that one of the more important benefits that could be achieved from using TEMS data for engine management concerned the development of test cell data and test cell schedules as well as the development of trouble shooting decision support guides. These areas consume a lot of CIP time and effort. However, these benefits could only be achievable if the TEMS was installed at the beginning of the service life of an engine. When a new engine type comes into service part of the CIP for that engine involves formulating trouble shooting guides and engine test cell running schedules as well as test schedules for fuel controls and other major components. If TEMS data were available to describe engine parameters during actual operation then these guides could be produced more accurately and would consume less time to produce. Current methods involve using manufacturer's data and collecting field experience and then using much trial and error to produce the guides.

Another area concerning the TF34 CIP manager involved the future loss of support by the engine manufacturer. SA-ALC MMP/BRE said that due to break-out competition and cost reductions, some of the information and data, previously provided by field service representatives, would no longer be provided at no direct cost. These services used to be paid for by surcharges on the price of spare parts but will become direct costs in the future. This erosion of contractor support will make the use of TEMS data for CIP management increasingly important and valuable. Further, the absence of these contractor services and transformed TEMS data will create a greater gap in the information available for CIP managers.

V. Conclusions and Recommendations

The objective of this research was to identify whether making Turbine Engine Monitoring System (TEMS) data available to an engine Component Improvement Program (CIP) manager in a usable format would produce better long term engine improvements under CIP than the data presently used. A subsequent objective was to establish if the TEMS data collected on the TF34 engine was being utilized by the TF34 CIP manager. Because the TF34 CIP manager does not use TEMS data to assist with CIP management, no direct analysis of benefits could be made. However, both the literature review and the CIP manager interviews offer strong support to the idea that TEMS data can be used to improve long term engine planning and in particular CIP planning and management. In particular, benefits in the areas of engine duty cycle determination, engine component life usage management, and component failure replication and diagnosis should be possible if TEMS data are used to assist CIP management.

Summary

All indications from both the literature review and the interviews with the CIP managers point towards the engine duty cycle as the key to CIP validity and success. Failure analysis, component redesign and Accelerated Mission Testing (AMT) relies on having an accurate and reliable understanding of an engine's operating environment and in particular its duty cycle.

Throttle position and engine RPM excursions were two parameters that were identified as being important for accurately identifying an engine's duty cycle. The process used to identify the duty cycle for the TF30 engine does not, however, include either of these two parameters. The method used for the TF34 engine does monitor the throttle position (power lever angle) but does not register RPM excursions.

This lack of essential information raises large doubts as to the accuracy and reliability of the duty cycles that are currently used by CIP managers. These doubts are further supported by other studies which have found that design duty cycles and CIP estimated duty cycles often grossly underestimate the actual duty cycle and operating environment of turbine engines (Birkler, 1980:9;Sallee, 1977:33;Vincent, 1980:109).

Both CIP managers that were interviewed believed that only a percentage of the fleet would require TEMS in order to provide the required data to determine the duty cycle (MMP/RES, 1987; MMP/BRE, 1987). Currently only twenty percent of the F-111 fleet have aircraft structural recorders installed. However, the British Engine Usage and Life Monitoring System (EULMS) trials (Birkler, 1980:73), found that the summation of small throttle transitions had a marked effect on the engine duty cycle. The trial also suggested that because every pilot flies his mission differently all engines should be monitored. Complete fleet monitoring is further supported if vibration and or thermal signature monitoring is required to assist with engine life usage monitoring. Each engine will require TEMS because every engine is different with respect to vibration signatures (Appendix A:52).

The current means of determining component lives and monitoring life usage depends on an accurate knowledge of the duty cycle. The penalties of not having an accurate duty cycle estimate include waste of useful life due to underestimating life usage and increased failure risk due to operation beyond actual life limits.

Another area in which the duty cycle affects engine CIP management is the AMT program utilization. More effective and efficient use of AMT test time could be made if an accurate test duty cycle could be determined.

The A-10, TF34 fleet is equipped with TEMS, yet these data are not being used by the TF34 CIP manager. All TEMS data recordings are down loaded to the Comprehensive Engine Management System Increment Four (CEMSIV) system at Barksdale AFB. These data are transformed for use by base level maintenance but are not available in a form that is useful to engineering or CIP management. The intent of the CEMSIV implementation was to install a link between the base level CEMSIV system and the CEMS central data base (CDB) (Fleming, 1982:Vol I, 14). The TEMS data would then be manipulated and transformed into useful information for engineering and CIP managers. However, this link between CEMSIV and the CDB has not yet been made (Appendix B: 55).

Without the CDB CIP managers cannot carry out any trend analysis and the amount of untransformed data is so great that any type of manipulation would be nearly impossible. Therefore the TF34 TEMs data are not currently being provided to the TF34 CIP manager or engineering managers in a usable format and the effort required to collate and transform the data is beyond current CIP capabilities. This lack of a CDB has also prevented a comparison between an engine CIP without TEMS data versus an engine CIP with TEMS data support. Such a comparison would have enabled the establishment of even stronger evidence as to whether TEMS should be installed on all engines, some engines, or not at all.

Conclusions

The missing connection between base level TEMS data collection and a Central Data Base (CDB) is preventing the TF34 CIP manager from utilizing TEMS data to assist in CIP management. If this connection is made and TEMS data can be used by CIP management, there is strong evidence to suggest that valuable benefits in engine development and CIP management can be achieved. In particular, the areas of engine duty cycle analysis, engine component life usage management, and component failure replication and diagnosis offer great potential for improvement.

The key to achieving benefits in the above mentioned areas is the engine duty cycle. Current methods used to estimate the engine duty cycle lack the accuracy and reliability that are required to manage modern gas turbine engines. The problem with these methods is that they rely on incomplete, inaccurate and unreliable data. The improvements offered by TEMS data include real time data, accuracy, reliability, and complete monitoring of important parameters.

Both of the CIP managers interviewed suggested that only a sample of an engine fleet would require monitoring and the size of the sample should be based on a cost-benefit trade off. In contradiction to this the British EULMS trials concluded that the entire fleet should be monitored. This will allow for accurate duty mission analysis, fleet trend monitoring, and engine signature analysis all of which require reliable and timely engine data for each individual engine. The idea of total fleet TEMS is futher supported for engine vibration signature analysis as every engine will display a unique signature.

Besides benefiting CIP management, the use of TEMS data should provide benefits in terms of reduced component wastage and improved flight safety. These should be possible through better component life management, reduced Accelerated Mission Test (AMT) running and test bench time as a result of better fault diagnostics, and better utilization of CIP funds through better long term planning.

Recommendations

The first recommendation resulting from this study is that the CEMSIV program be completed as first planned by implementing the connection between the TF34 base level TEMS data collection and a Central Data Base. This will allow the TF34 CIP manager to carry out fleet trend analysis and to accurately identify the TF34 duty cycle. Second, following a twelve month operational period, a new study should be carried out to compare engine CIP management without TEMS data versus engine CIP management with TEMS data support. This analysis should also include a comparison of the usage and duty cycle of individual TF34 engines within the fleet. The purpose behind this is to establish if full fleet implementation of TEMS is justified.

Twelve months was chosen as the period because two engine CIP conferences will have been conducted during this time. Management of engine CIP problems is summarized and updated at these CIP conferences along with the reporting of progress on redesigns, modifications, and AMT testing.

The third recommendation is that a cost analysis should be carried out to establish if the benefits achieved in both long term and short term engine support justify a full implementation of TEMS and CEMSIV. The importance of this is that if it does provide adequate insights, then other engine types should implement TEMS programs.

Finally consideration should be given to application of TEMS to new aircraft systems. During the CIP manager interviews MMP/RES stated :

> "One of the most important benefits to engine system development is provided only if the TEMS system is developed and installed in the initial stages of an engine's service life. Large savings in dollars and manpower could be achieved by reducing the time taken to develop trouble shooting guides, test cell data and test schedules, and component failure test procedures (especially fuel controls) (Appendix A: 54)."

TEMS programs should be considered for new systems such as the C-17, ATF, ATB, and new F-15 and F-16 programs to provide maximum utilization of the accurate duty cycle information and fault diagnostics provided by TEMS data.

Appendix A: Telephone Interview 1

Record of Interview with TF30 CIP Manager

Office Identification : TF30 Engineering Unit Chief
Engineering Reliability Branch
OC-ALC MMP/RES

1. How long have you been associated with TF30 CIP?

ANSWER: The current MMP/RES has been manager of the TF30 component improvement program and involved with TF30 engineering since 1967.

2. What is the operating environment of an aircraft engine?

ANSWER: The operational environment of an engine involves all inputs and outputs dealing with producing a propulsive force. This includes fuel and air mass flow, throttle movements, operating temperatures, and engine revolutions per minute (RPM) excursions and how these parameters influence the lives of major rotating components such as compressor disks and turbine assemblies.

3. How is an understanding of the operating environment of the TF30 engine obtained?

ANSWER: The operating environment is determined using two methods to enable cross checking. The first process involves field visits to the various F111 operational squadrons during which discussions are held with maintenance personnel and operators. In particular, pilot interviews are conducted to determine power lever (throttle) angles and movements during approved missions. The second process uses data that are recorded on the aircraft structural recorder which is fitted to twenty percent of the F111 fleet. This device records many aircraft cyclic events which includes altitude, gross fuel flow, and mach number. These data are used to compile a limited picture of the engine operating environment and are cross checked using the field visit interviews.

4. How is the mission profile established for the AMT duty cycle?

ANSWER: The AMT engine duty cycle, which is used to simulate the in-service environment of the TF30 at an advanced usage rate, is developed by the engine manufacturer (Pratt & Whitney) under CIP using data from the aircraft structural recorder tapes and the field trip interviews.

5. Would possessing a better understanding of the engine operating environment help to expedite resolution of reported component failures?

ANSWERS: In some instances having a more complete picture of the operating environment would help but it would depend on the problem and the circumstances. In particular, fuel control problems, engine stalls, and engine over-temps at take off are problems where a better understanding of the operating environment at the time of occurrence would assist in developing a solution.

6. What data would help to establish a more accurate duty cycle?

ANSWER: The most important flight data for correctly identifying the engine duty cycle is an accurate record of the power level angle and RPM excursions during aircraft missions.

7. Would having continuously recorded flight data help to establish more accurate aircraft mission profiles and hence more accurate engine duty cycle?

ANSWER: Yes, without any doubt. However, these data would not be required for every aircraft. Only several aircraft from each squadron or different mission area would be required. The number of aircraft equipped to record such data would depend on a cost trade off between benefits and installation expense. Also, the CIP manager would not require this type of data continuously as this would result in an accumulation of data that would probably end up not being processed or used. A CIP manager would only require the information on a random basis.

8. If a more accurate duty cycle could be established using flight data, do you believe this would give greater confidence in AMT results and hence reduce CIP qualification time?

ANSWER: Yes it could reduce qualification time. The current procedure for gaining confidence in AMT results, especially if the cause and effect of the original problem is unknown, is to compare the results at various stages with actual in-service experience. Using actual flight data to develop the AMT for a new or redesigned component could remove the need to compare results with field experience. Qualification time would be reduced in two places. The first place would be in the design of the AMT and the second would be time saved by not requiring to check against field experience. The amount of actual AMT time saved would be dependent on the nature of the ongoing investigation.

9. If more accurate and reliable engine cycle data were available would it change your management of LCF life limited components?

ANSWER: Yes. If accurate in-service engine cycle data were available then, when determining LCF lives, fewer assumptions would be required and the component life would not be assessed as conservatively as it is now. The component life is determined in engine hours which are derived from a cycle to hour ratio. This ratio is derived from the mission profile and estimated engine duty cycle. With a better understanding of actual engine cycling and crack propagation components could be used for a longer life than is currently assigned. Once again a cost benefit analysis would be required to determine if the extension in life would warrant the expense. In addition, a more accurate picture of the engine duty cycle may force LCF lives to be reduced because a more rigorous cycle usage could be revealed. Another advantage would be where aircraft at two different squadrons fly very different missions and hence would have different duty cycles. If cycle usage could be monitored accurately then, components could be allocated different LCF lives for the different missions.

10. If accurate data were available for thermal cycles and vibration signatures for in service engines do you believe qualification testing could be reduced?

ANSWER: This is hard to answer directly as every engine is different when it comes to accurately recording thermal or vibration patterns. Knowing the vibration signature and thermal history at the time of a failure could reduce AMT run time because you would know exactly what to simulate to replicate failure conditions. Another benefit would be that CIP engineering would be better prepared to determine whether a modification or a redesign is required. In addition, during redesign, the engineers will not have to be as conservative with material design if accurate thermal and vibration data are available.

11. What is the basis for assigning priorities to items under CIP?

ANSWER: The first priority is assigned to items that involve flight safety and involve grounding of aircraft. The next level of priority is assigned in terms of failures that are costing the most. This can include the cost of actual component failure and replacement or the cost of an engine returning to the maintenance centre before it is due. The final level of priority is assigned in terms of expected return on investment mainly referring to reliability, durability, and maintainability.

12. Do you think having access to fleet wide TEMS data could change the way in which CIP priority is attached to failures or problems?

ANSWER: I believe it would probably have little bearing on the way in which priorities are assigned. It could probably help determine if a problem is unique or is a fleet problem. If this occurs then the priority assigned to such a problem would be different. Additionally, TEMS data could help to detect flight safety or reliability trends before they become life or mission critical. This would force CIP involvement earlier than without TEMS data.

13. Do you believe that access to TEMS data could change forecasting for engine development and hence change CIP fund management?

ANSWER: If actual failure trends could be identified the CIP involvement would occur earlier because you would not have to wait until a trend is identified following a series of component failures. Such trends are not always easily identifiable because the cause of the problem or failure is not always easily identifiable.

One of the most important benefits to engine system development is provided only if the TEMS system is developed and installed in the initial stages of an engine's service life. Large savings in dollars and manpower could be achieved by reducing the time taken to develop trouble shooting guides, test cell data and test schedules, and component failure test procedures (especially fuel controls).

Appendix B: Telephone Interview 2

Record of Interview with TF34 CIP Manager

Office Identification: TF34 Project Engineer
SA-ALC MMP/BRE

1. How long have you been associated with TF34 CIP?

ANSWER The current MMP/BRE has been manager of the TF34 CIP since 1982.

2. Do you use TF34 TEMS data to assist with the management of the TF34 CIP?

Answer: No. TEMS data are not used directly or on a regular basis. Under the CEMS IV increment a Central Data Base (CDB) was to be established which would have provided formatted, compiled TEMS data. However, the building of a CDB for CEMS IV has been suspended and only the base level parts of CEMS IV will be implemented in the near future.

Without a CDB the data from TEMS are too extensive and unstructured for use in aiding CIP management. For efficient CIP use of TEMS data you need to be able to review fleet wide data for a particular problem. This is not easily accomplished, if it can be done at all, because of the large amount of data involved.

3. Do you use TEMS data at all?

Answer: Yes. Sometimes TEMS data are extracted for a particular problem if there is difficulty in correctly reproducing cause and effect at failure. In addition there is currently a project in development to extract fuel control failure data from TEMS for a specific data base to assist with trouble shooting.

4. Could using TEMS data assist or change the way in which the TF34 duty cycle is defined to match the A-10 mission profile?

Answer: TEMS data could be used to develop the duty cycle but enough data are already available from the A-10 Velocity/Gravity/Height (VGH) tapes which record many aircraft parameters as well as engine parameters including throttle lever angle. This allows for accurate duty cycles to be defined. However, the VGH data are not received frequently enough and result in the mission profile assessment being dated in many instances and hence reduces the confidence in the accuracy of the duty cycle.

5. If TEMS data were available to the TF34 CIP, in a usable format, would the accurate and reliable engine cycle data that is recorded by TEMS change the management of LCF limited components and in what way?

Answer: Yes. TEMS data could be used to tailor LCF lives for specific missions at the different operating bases and hence achieve longer component lives in some instances (this is tied to question 3). Because of the accuracy and reliability of TEMS data it would also assist in the analysis of LCF lives and make the estimated lives less conservative and hence extend some lives.

6. If accurate and reliable data were available for engine thermal cycles and engine vibration signatures do you believe that the amount of qualification testing could be reduced?

Answer: These data could possibly be used for duplicating failure conditions. However, there is a lot of statistical spread in such data and it may not reduce test time. If a historical base was developed perhaps an understanding of the spread could be developed and then the information could be more useful. Because of these unknowns it is hard to say if AMT test time could be reduced.

7. What is the basis for assigning priorities to items under CIP?

Answer: First priority is given to flight safety items. However, beyond this there is no rigid system for assigning priorities. Assignment of priorities is very judgmental and is mainly based on a risk vs cost trade off analysis. The next major consideration after flight safety is usually life cycle cost.

8. Do you think that having access to fleet wide TEMS data would change the way in which you assign priorities to CIP items?

Answer: Yes. TEMS fleet wide data could be used to distinguish fleet wide trends from isolated incidents. As stated in question 2 this would be especially useful for trouble shooting fuel controls. This type of fleet wide data would also allow engineering to home in on the more important problems and hence possibly allow for better management of CIP funds.

9. Do you believe that having access to fleet wide TEMS data could assist in forecasting engine development requirements and hence better management of CIP funding?

Answer: Yes. TEMS data would be especially useful in trending fleet wide deterioration and planning a replacement schedule. Because the degradation can be anticipated the costs would be greatly reduced and CIP involvement could be stretched across many years rather than having to allocate a large amount of CIP funds when failures, reliability, or performance problems are detected.

Additional Comments: During the past operation of the TF34, CIP management has been greatly assisted by information and data supplied by the engine contractor General Electric (GE). These data came from the many GE field service reps that monitor engine activity at the bases. However, due to cost reductions and competition GE has been removing some of the services and information is no longer freely available. In fact information that used to be provided as part of support agreements paid for through spare parts pricing now has to be paid for. I predict that contractor provided support will be further eroded and hence use of TEMS data for CIP management will become much more attractive.

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Vita

Squadron Leader Len J. Neist was born 10 October 1956 in Sydney, Australia. He graduated from high school in Homebush, Sydney, in 1974 and attended the University of Wollongong, from which he received the degree of Bachelor of Engineering in Mechanical Engineering in May 1979. Whilst at university he received a commission in the Royal Australian Air Force as a Pilot Officer through the Undergraduate scheme. Upon graduation he was promoted to Flying Officer and was ordered to Officer Training School in January 1979. Upon graduation from OTS in April 1979 he served as Base Engineering Officer at No1 Stores Depot, Tottenham, Victoria. On 1 July 1981 he was promoted to Flight Lieutenant. In December 1981 he was ordered to No2 Flying Training School, RAAF Base Pearce, Western Australia, where he served as Officer In Charge (OIC) of Operational Level and Flight Line Maintenance and later as OIC Maintenance Support Flight. In February 1984 he was ordered to Head Quarters Support Command, Melbourne, Victoria, to the position of AIRENG2A4, System Engineer for the TF30-P3 and JT3D turbo-fan jet engines. During this time he represented the RAAF at the 1985 and 1986 TF30 Component Improvement Program Conferences at, West Palm Beach, Florida. In May 1986 he was ordered to RAAF Washington for assignment to the School of Systems and Logistics, Air Force Institute of Technology.

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Abstract

The purpose of this study was to identify if the data collected by Turbine Engine Monitoring Systems (TEMS) could benefit an engine's Component Improvement Program (CIP) management.

The initial plan was to identify and assess any benefits by comparing an engine with a CIP (PWA TF30) but not TEMS against an engine with a CIP and a TEMS (GE TF34). This was not possible, however, because the TEMS data were not being used to assist with TF34 CIP management because of the lack of a Central Data Base to collate and transform the data.

Data were collected via telephone interviews with the two engine CIP managers and via a literature review. Analysis of the data provided sufficient evidence to indicate that the current methods used to estimate and track the engine duty cycle in both the TF30 and TF34 engines use potentially unreliable and inaccurate data. Sufficient evidence was also identified to indicate that TEMS data could provide more reliable and accurate engine cycle data which would improve and hence benefit CIP management.

The engine duty cycle was identified as the key to many important areas of a CIP, including engine component life usage and failure replication and diagnosis. As mentioned in the previous paragraph, the current methods used to identify an engine's duty cycle lack the accuracy and reliability that are required to manage modern gas turbine engines.

The main thrust of the recommendations is that a central data base be established so that the TF34 CIP manager can utilize TEMS data. In addition, a comparison using cost analysis is recommended to firmly establish the benefits to both long and short term engine management.

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